

MYRIADE: CNES Micro-Satellite Program

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Abstract

CNES is currently leading the development of a program of micro-satellites, which has been now blessed with a name in line with the ambition: MYRIADE.

The intention is to primarily fulfill the needs of the national scientific research in small space missions. Technology experiments as well as demonstration flights for new mission concepts shall however not be forgotten. The main objective is to make access to space much easier and affordable. The first five scientific and technological mixed missions (which include international cooperation) are under realization and fully funded.

The program foundation is strengthened by a specification for a product line with enough flexibility allowing adaptation to each mission.

The product line will also support other applications for commercial or national needs. Partnership agreements have been implemented to that effect with ASPI and ASTRIUM. These leading European space companies will be in the micro-satellite trade as a compensation for their contribution to the CNES-led development effort.

Construction of satellites at a rate of at least two per year shall be made possible by an industrial structure been set up by CNES in parallel to the development.

The strategic objective of CNES is to keep authority on the concept and control of the system by overseeing capability and performances requirements, in concert with the scientific investigators and laboratories. Capacity to implement technological innovations shall also be a cornerstone of MYRIADE endeavor.

CNES is contracting with equipment suppliers and has also selected LATECOERE for the AIT activities of the first micro-satellites. This company shall eventually be responsible for the satellite adaptation and therefore it shall tailor the original definition of the functional chains to the specifics of each new mission.

Introduction

MYRIAD is a program related to micro-satellites. It follows the path of PROTEUS that is a similar CNES undertaking for small satellite development.

It was therefore decided to found a micro-satellite project organization, with CNES having a prime role for controlling the

industrial organization and setting up the methods and tools to allow adaptation of the product to each mission in a low cost as well as a short time schedule objectives. PROTEUS development is done in partnership with ALCATEL SPACE, whereas the later and ASTRIUM are both partners of CNES for MYRIADE endeavor.

The mass of the typical satellite is 120kg. It shall be compatible for launch as a secondary payload on ARIANE 5, PSLV or DNEPR. Opportunities of launch on STARSEM/SOYOUZ, ROCKOT and other launchers are also considered.

It is intended to perform a given scientific mission at a cost objective of M€ 10 (payload development being excluded but launch and operations are included).

The main goal of the MYRIADE program is to develop a product line based on adaptable functional chains. Having those on the shelves shall allow to

- Satellite at a low cost
- A short development duration
- While keeping a strict frame of Product Assurance.

These characteristics allow a new programmatic approach as:


- To decide a short schedule program offering the best phasing with technology evolution and permitting incoming
- To take risk at a higher level : programs with uncertain scientific return can be decided, the scientific improvement perspective being very attractive compared to the funding
- To create opportunities for international cooperation
- To give complementary offers for access to space for new partners like Universities.

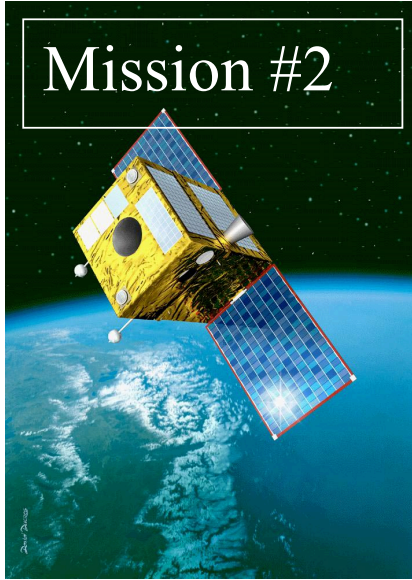
Average capability of doing two of such a mission per year from various thematic domains like Earth Sciences (Solid Earth, Atmosphere,

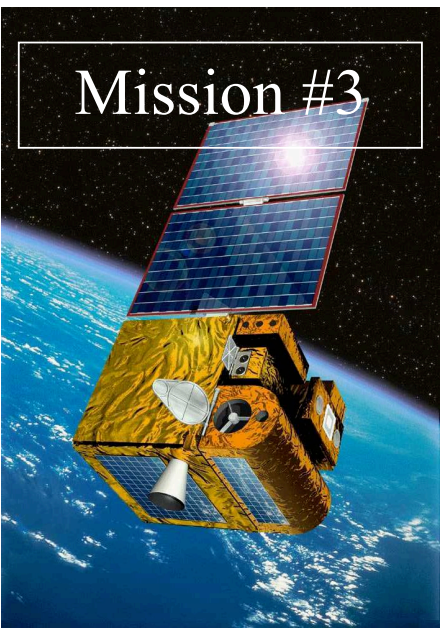
Biosphere) and Science of the Universe (Astronomy, Planetology, Physics of Plasma, Fundamental Physics. Such a pace justifies the name recently given to this program: MYRIAD (In French: Myriade).


The first Myriad Scientific Missions

A yearly process leading to the selection of a renewed batch of scientific space missions to be considered and the couple of those that shall be incorporated in the flight list is currently going on. It shall complement the five first ones that were selected before that summarized below:

DEMETER	
<p>Mission</p> <ul style="list-style-type: none"> Scientific : Ionosphere perturbations linked to earthquakes Technology : In flight validation of newly developed component (Autonomous Orbit Control, HDTM) ... <p>Orbit & Pointing principle</p> <ul style="list-style-type: none"> Polar Low Earth Orbit 700 Km 10H30 Earth pointing <p>Satellite</p> <ul style="list-style-type: none"> Total mass: 120 kg <p>Payload</p> <ul style="list-style-type: none"> ICE: Electrical: CETP IMSC: Search-coil LPCE IDP: Particles CESR IAP: Plasma CETP ISL: Langmuir: ESTEC <p>Launch : EARLY - 2003</p>	

FRENCH BRAZILIAN MICRO SATELLITE	
<p>Mission</p> <ul style="list-style-type: none"> Scientific : Particles measurement Plasma analysis Technology : In flight validation Space environment analysis <p>Organization</p> <ul style="list-style-type: none"> Joint development CNES / INPE <p>Orbit & Pointing Principle</p> <ul style="list-style-type: none"> Equatorial. Low Earth Orbit 700 KM 6° Sun pointing <p>Satellite</p> <ul style="list-style-type: none"> 110 kg <p>Payload</p> <ul style="list-style-type: none"> Science : 5 instruments Technology : 5 experiments <p>Launch: 2003. VLS</p>	

PICARD	
<p>Mission</p> <ul style="list-style-type: none"> • Simultaneous measurements of solar diameter/ differential rotation, solar constant, and variability. <p>Orbit & Pointing Principle</p> <ul style="list-style-type: none"> • 6h-18h SSO 700 Km • Sun pointing <p>Satellite</p> <ul style="list-style-type: none"> • Total mass: 110 kg <p>Payload</p> <ul style="list-style-type: none"> • SODISM: UV telescope: 100 mm. CCD • SOVA: • UV photometers • PI: Service d'Aéronomie <p>Launch : Mid 2006</p>	

PARASOL	
<p>Mission</p> <ul style="list-style-type: none"> • Climatology : study of Atmosphere, and Continental & Oceanic biosphere. • Laboratoire d'Optique Avancée (Lille) <p>Orbit</p> <ul style="list-style-type: none"> • Sun Synchronous Orbit 12H 700 Km • Formation flying with Cena, AQUA, CloudSat <p>Satellite</p> <ul style="list-style-type: none"> • Options : Propulsion, GPS, High Data Rate Telemetry <p>Payload</p> <ul style="list-style-type: none"> • POLDER derived instrument : • POLarization and Directionality of Earth Reflectance. <p>Launch : Early 2004</p>	

MICROSCOPE

Mission

- Verification of the Principle of Equivalence between Inertial & Gravitational Mass

Orbit. Pointing principle

- 6h-18 H 700 Km SSO
- Spin : 2ω

Satellite

- Mass: 105 Kg
- Drag free
- Ionic propulsion: FEEP

Payload

- 2 electrostatic differential accelerometers (ONERA)

Launch : End 2004



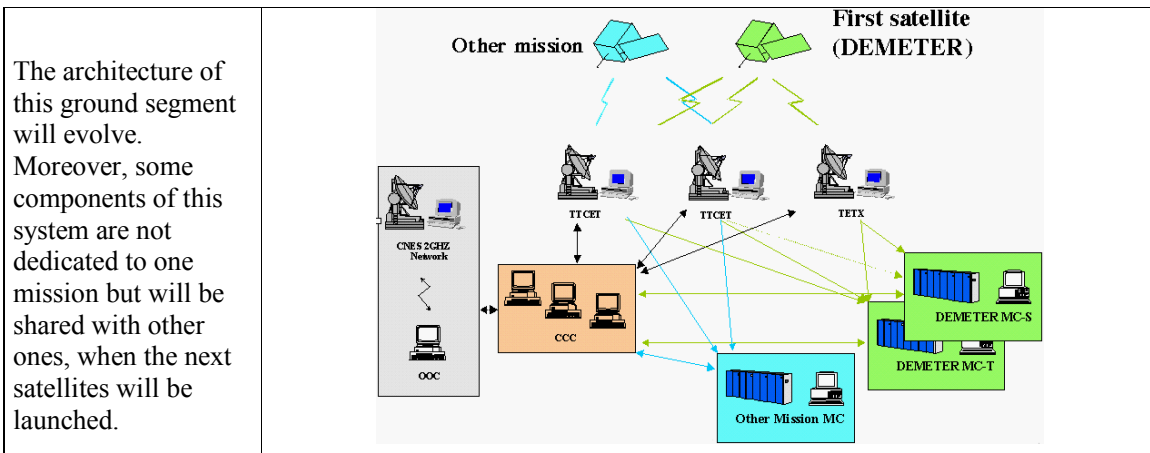
System Description

Main Features

MYRIAD product line is characterized by a its high performance design in terms of capability offered to the payload (mass, power, pointing accuracy and agility, telemetry and processing). Low cost objective is met in part by use of COTS (parts and equipment), together with the utilization and use of innovative methods of Systems Engineering.

The MYRIAD micro-satellite program is based on a simple rationale:

- A reference subset of functional chains is initially fully developed and qualified for the first mission (i.e. DEMETER).
- Optional functional elements are completely studied in parallel to enable further other different missions. Most of them will fly on DEMETER as experiment even though they are not required by the main mission.
- Models and simulations, mostly but not exclusively software, allow fast study of any new mission in the frame of the Engineering Center.
- A MYRIAD ground system for multi-mission control is created. It is composed of:
 - a Command Control Center (CCC)
 - one Telemetry and Tele-Command Earth Terminal (TTCET)
 - a Data Communication Network (DCN)
 - an X band Telemetry Earth Terminal (TETX)
 - two Mission Centers (MC), one for the scientific part of the mission (MC-S) and the other for the technological one (MC-T).



.Figure1: MYRIAD Ground Segment

This system has the additional capability to use CNES multi-mission resources (CNES S-band stations network and the Orbitography Operational Center). These resources can be

used for orbital station acquisition and in case of anomaly.

Satellite Main on Board Functional Chains: the Hard Core of the Myriad Product Line Development)

The satellite architecture is mainly based on the following functional chains:

The Attitude and Orbit Control Function

which includes:

- An attitude determination system based on 3 coarse Sun Sensors (only used for the Acquisition and the Safe Mode), a 3-axis Magnetometer and a Stellar Sensor when precise attitude measurement is needed or when pointing accuracy must be better than few degrees. Three raw gyros (1-axis gyros) are added to the design to give attitude information during orbit maneuvers
- An attitude control system based on the use of up to 3 reaction wheels (fine attitude control and maneuverability) and 3 magneto-torquers to unload the reaction wheels or control the coarse attitude mode.
- An optional orbit control system comprises a hydrazine propulsion subsystem with four 1N thrusters. This is the minimum configuration to have orbit maneuvering capabilities as well as 3-axis attitude control during maneuvers.

The Electrical Power Generation, Regulation and Distribution Function

includes:

- One steerable AsGa solar array (with 2 deployable panels),
- One 11 Ah Lithium-Ion battery,
- A power regulation and distribution box.

The power is delivered to the payload equipment through up to 22 non-regulated busses. The solar array could be fixed (Sun pointing mission) or oriented with a one-axis mechanism around -Y axis (i.e. normal to the

orbit plane). The cant angle of the deployed solar array will depend on the mission requirement.

The Control - Command Function

is mainly supported by:

- A central On Board Computer (OBC), including a 1 Gbits memory, based on a transputer T805 and several micro-controllers (PIC 16C73) for interfacing with the equipment.
- Two S-band link transmitter and receiver chains associated with two antennas (Tx /Rx) produce a quasi-omnidirectional coverage. The TM data rate is 400kbits/s in operational modes and 25kbits/s in safe modes.

This functional chain will be slightly adapted for each mission, depending on specific requirements. For example, DEMETER shall supplement an X band telemetry chain to the basic S-band, and the following features are taken into account in addition for the mission:

- High satellite inertia and low natural frequencies due to some large appendages (booms),
- Magneto-torquers activation limited to orbital period free from scientific measurements (terrestrial high latitudes > 60° and <-60°)
- Specific EMC requirements (e.g. ITO coated solar array).

Satellite Mechanical and Thermal Architecture

The satellite structure and thermal control shall be customized for each mission, except in the case when the basic structure is able to accommodate the stated requirements coming from the payload for the corresponding mission. The main drivers of the satellite architecture are:

- Use of a generic very rigid lower plate (interface with the launcher), including optionally a shock damper system,
- Design of a modular architecture with an independent propulsion module directly integrated on the lower plate,
- General design concept (mechanical, power generation and attitude control) allowing to systematically have a satellite face in the shadow. This face supports low

temperature equipment (e.g. battery) and the stellar sensor, which requires not only low temperature but also a field of view without any sun parasitic illumination.

The following figure shows the basic structure (spacecraft bus only shown), with the propulsion module and the lateral panels. The 2 solar array panels are folded on the -Y face, opposite to battery and stellar sensor +Y face, as shown on the figure on the right.

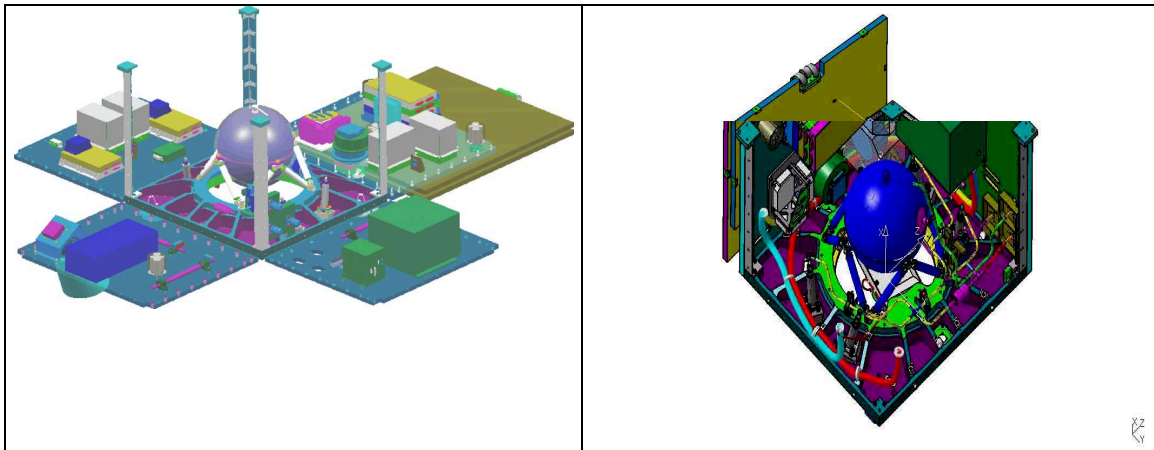


Figure 2: Structural principle for the first Spacecraft

Launch Means

In addition to ASAP ARIANE 5 (ARIANESPACE) opportunities, launchers such as PSLV (ANTRIX), DNEPR (ISC KOSMOTRAS) and ROKOT (EUROKOT) are considered for placing MYRIAD micro-satellites into LEO. SOYOUZ (STARSEM) could also be used if some opportunities materialize in its manifesting.

ASAP 5 can accommodate up to eight auxiliary passengers.

PSLV has the capacity to launch up to two micro-satellites in addition to the main passenger.

DNEPR, in its basic configuration, has a capability to launch typically four to five micro-satellites together.

ROKOT has recently entered the commercial trade for up to six auxiliary payloads.

Some obvious differences can be noticed in the mechanical interfaces and umbilical links capabilities from one launcher to another. We have however found that adaptation to any of those can quite easily be done. As the other launchers requirements are similar to the requirements for an ASAP 5 micro-satellite launch but with lower environmental loads (e.g. shock and random), dimensioning was therefore done on the basis of ARIANE 5 requirements.

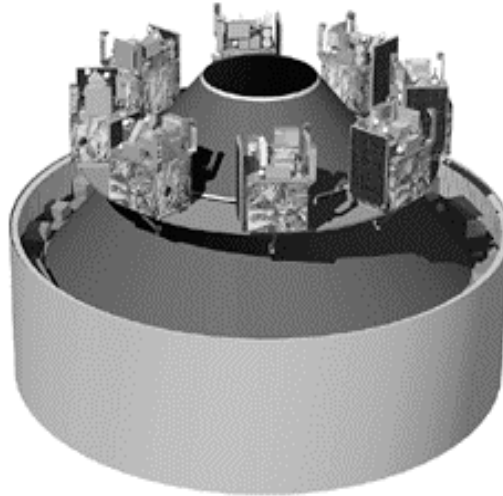


Figure 3: ARIANE 5 ASAP configuration.

Satellite Main Technical Budgets

Mass budget: DEMETER weighs about 115 kg. This comprises avionics (19 Kg including payload management, its memory and the X-band telemetry), structure and thermal (34 Kg), power supply (19 Kg), propulsion (8 Kg) and payload (35 Kg).

Power budget: the photovoltaic array outputs 160W maximum of power at 70deg C and after one year in orbit. The solar array configuration (with a cant angle of 14deg and the local hour variations of the 10: 30 orbit ascending node for DEMETER) yields a maximum permanent available power higher than 80W, and up to 90W during the X band TM transmission.

Attitude control performances: the raw attitude control Mode gives an accuracy of less than 5deg. The Stellar Sensor boosts the attitude control accuracy to better than 0.1deg (3 sigma)

worst case and measurement accuracy is then better than 0.01deg.

Research and Development

R&D effort is still currently being pushed in order to make advanced technology equipment available and in line to the present or future needs of the Myriad technical and cost goals.

R&D that was initiated in 1997 for OBC and S-band receiver/transmitter (RX/TX) have already produced the core of the current MYRIAD spacecraft Avionics described before in this paper.

- For OBC, the goal was to reduce dramatically cost, mass and consumption for a performance at the level of the state-of-the-art computers used in current projects. A 3Kg/5w/2 liters/2 Mips/ 1Gbits/ 15Krad goal was assigned. Performance as such was not really challenging as SPARC X processor, memory and rad-hard parts were the reference. Challenge was to get it cheap. Use of new architectural solutions was felt necessary.

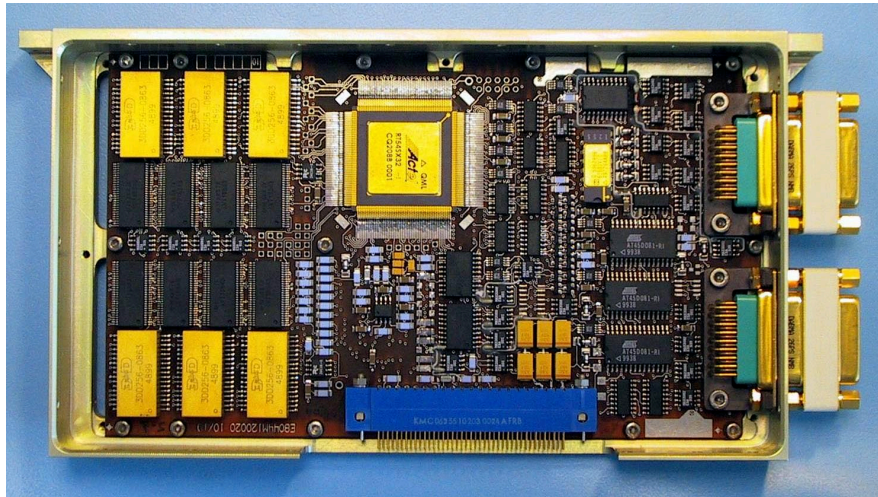


Figure 4: OBC CPU Processor board

Conventional printed circuit boards that are populated on both sides with plastic surface mounted parts (FPGAs and processor are however in ceramic packaged) are adequately mass efficient. By using internal serial buses for connecting the four basic modules (i.e. Power, TM/TC, CPU and I/O), a network was designed that provides enough adaptation margins. This is a direct application of what everybody sees when he uses a PC connected to a network. For external interfaces the opposite was done, avoiding buses to simplify software but using direct and dedicated RS485 links. As the processor is not latch-up immune, specific circuits protect and allow a reboot of the computer when non recoverable error occurs.

Some “system hidden” redundancy scheme was implemented for each critical internal node (watchdog and over-current protection against heavy ion effects, coded command against failure propagation). This is our way to live with COTS parts. A small number of rad-hard parts are however part of an internal safe management core.

- For the RX/TX equipment, miniaturization and technology coming from the commercial market were used. Low cost/low power/low volume resulted from procurement of macro-parts coming from digital TV or mobile phone electronic mass-production (e.g. ASICs for decoding and demodulation in TV receivers). While acknowledging the dynamic background

in term of innovation and reliability, these parts have undergone a complementary tests program (i.e. temperature, radiation...). This carefully adapted and slimmed test program did preserve overall cost reduction in reducing integration, performance and global cost. Other functions are achieved in more conventional hardware but always with more advanced technologies (multi-layer circuits, CMS parts, automatic report as for radiotelephone devices).

Contracting with new industrial partners with no prior space experience was completed with strong involvement and interaction from our side. A careful strategic parts procurement, and full qualification tests campaign was also necessary.

These unusual efforts have given rewards however: comparing to standard equipment for other space project, both power consumption and volume have been cut by a factor of 2. Recurrent cost was slashed by a figure 5 to 10!

Ground Satellite Interface

The communication between the ground segment and the satellite is performed through two links: the S band, and the X band. The S band link is fully compliant to the CCSDS standard, whereas the X band link complies with this standard at the packet level.

The X band is devoted to scientific telemetry, whereas the S band is used for housekeeping and

technological telemetry or to scientific missions with limited data transmission needs (up to 600 Mbytes/day). All the TC are transmitted through the S band, using a protocol which guarantees automatic re-transmission of TC frames detected as erroneous or lost by the board peer.

For the S band, the specified performance objectives must be guaranteed for a minimum elevation of 10deg with a system margin of 3 dB for TM and 10 dB for TC. The frequency, modulation and rate characteristics of the interface for LEO satellites are stipulated in the following table:

Table 1: S-Band characteristics

S band	Safe mode	Nominal mode
TM Modulation and coding	QPSK (1/2 Nyquist filter) Viterbi RS concatenated coding	QPSK (1/2 Nyquist filter) Viterbi RS concatenated coding
TM Modulation and coding	QPSK (1/2 Nyquist filter) Viterbi	QPSK (1/2 Nyquist filter) Viterbi
Maximum telemetry rate	25 kbits/s	400 kbits/s
Telecommand rate	20 kbits/s	20 kbits/s

For the X band, the specified performance objectives must be guaranteed for a minimum elevation of 15deg with the X-band ground station. The maximum data coded rate is 18 Mb/s. The modulation and coding used is a Multidimensional Trellis Coded Modulation Concatenated with Reed-Solomon bloc code (MCTMCRS).

Command and Control Ground Segment (MIGS)

The MIGS inherits of the PROTEUS Generic Ground System.

The CCC (Command Control Center) is in charge of:

- Preparing the programming messages taking into account the payload part which is built in the Mission Centers,
- Preparing and monitoring the communication with the satellite using a TTCET,
- Reconciling the TM for a quick look and for alarm generation,
- Evaluating the functioning of the spacecraft bus,

- Orbit and attitude monitoring.

The CCC performs the orbit restitution using Doppler measurements acquired by the TTCET. The Data Remote Processing PC (DRPPC) is a PC which can be used in the CCC or outside, in order to process real time housekeeping telemetry, or to work with the archive data that are stored in the CCC databases.

From an labour point of view, the ground operators work only during administrative hours. This requires:

- The capability of performing automatic loading of programming messages in the absence of any operator, using an agenda function,
- An automatic anomaly detection.

The TTCET are automatic S-Band stations, in charge of:

- Establishing and maintaining the satellite to ground radio-frequency link for all programmed visibility passes (transits),
- Receiving and temporarily storing the received telemetry during a transit. This function concerns the House Keeping

Telemetry to be Recorded, but also a part of the Payload Telemetry,

- Receiving and transmitting to CCC the Passage House Keeping Telemetry during a transit,
- Accepting the connection with CCC or a Mission Center for transmission of payload data and a part of the received spacecraft bus data,
- Transmission of command to the satellite for the transit in progress,
- Doing Doppler measurements during the transit, for orbit calculation and antenna positioning,
- Compensating Doppler effect on Command link,
- Contributing to the on board with UTC time synchronization.

The TTCET is equipped with a 3.1 meters diameter antenna.

The last component of the MIGS is the Data Communication Network (DCN). Its main characteristics are:

- The interfaces of the MIGS are based on Internet Protocol (IP), for real time transfer via service sockets, or file transfer using ftp
- The MIGS subsystems are connected to the IP network by standard routers.

Industrial Organization

Organization for Development of MYRIAD

CNES is prime contractor for the MYRIAD line of product development:

Engineering of the MYRIAD System is performed and led by CNES with some links with the PROTEUS product line development.

Depending on the scientific mission CNES may also performs engineering and AIT of the payload. Otherwise this is a task for the Laboratory.

Spacecraft engineering is also performed by CNES which specifies, contracts for and oversees the R&D effort. This engineering is done in partnership with ASTRIUM and ALCATEL

ASTRIUM is involved in:

- Software specification and validation,
- Software test bench development,
- Some of the AOCS modes studies and development.

ALCATEL is involved in:

- PCDU (Power Conditioning and Distribution Unit) development
- Solar Array development.
- Software test bench

LATECOERE was contracted for spacecraft integration and testing. This company shall eventually be responsible for the satellite adaptation and therefore it shall tailor the original definition of the functional chains to the specifics of each new mission.

Industrial organisation for the routine phase

In the routine phase, the recurring equipment procurement and the AIT engineering will eventually be assumed by LATECOERE.

In order to be able to answer the demand of any Prime Contractor (then in charge of satellite engineering) or in the case of commercialisation of the micro-satellite product, LATECOERE activities shall be extended to allow mechanical /electrical software adaptation to this Prime requirements.

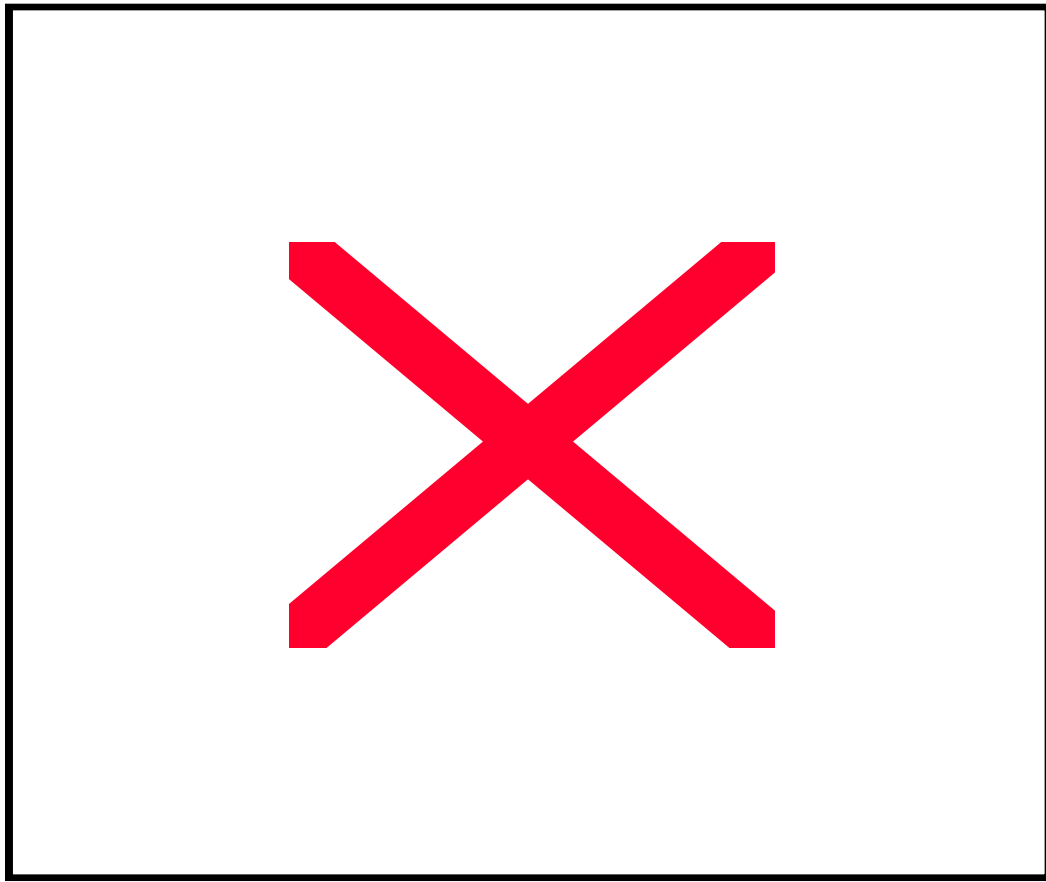


Figure 5: Industrial Organization for the routine phase

Conclusions

The field of past, existing or planned micro-satellite through the world is quite diverse in their characteristics: Some spacecraft are simplified to the extreme and other are ambitiously sophisticated.

CNES has taken into account the wishes which were expressed by the French Scientific Community to come to a specification set for the micro-satellite leaning on the upper end of the scale.

The resulting product of the MYRIAD program shall then be very capable, versatile and efficient. In every aspect that has been surveyed so far, the demand of the end-user is satisfied.

Integration and test of the first item of the MYRIAD family, DEMETER, shall start this coming fall. It is time to look back and enjoy having developed a product, which holds the promises of being at the specified and intended cost level while not impairing its ability to totally fulfil the needs.

In contribution or in addition to this result, an industrial organization has been settled and both industrial Spacecraft Primes -ASTRIUM and ASPI- have been associated to the development through engineering partnerships which allow them to use the design for their own applications. Numerous requests for proposals were issued to International Companies worldwide as to select

the best equipment at the lowest price. When this was obviously not existing on the market, our own R&D has responded.

New Systems Engineering processes have also been deployed. This applies for development of the initial items as well as for the settlement of the engineering force and workshop to prepare the definition of the up-coming scientific missions, which shall soon follow the five first one that are already undertaken.

The MYRIAD program is one of the opportunities for applying the trends of the Strategic Plan defined by CNES. New ways to adapt us to the evolution of space activity, either through the use of other resources from economical sectors have been tried. COTS components are extensively used as well as innovative technology or methodology.

The MYRIAD micro-satellite product line encompasses a subset of tools and functions (equipment, software, architectures, simulation test bench, and engineering workshop). Besides the ability to fulfil the space scientific needs for micro-satellites, plans are already drafted in order to expand to industrial organization for producing, and, when needed, commercializing this product. This, in the long term, will allow CNES to concentrate back on its assigned main role of system and satellite prime responsibility for its own scientific and technological applications, or for International Cooperation.